

States and prospects of laser drivers for 250W and toward > 500W extreme ultraviolet (EUV) generation

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1. Who we are

Key machines supplier for emerging healthy markets

**最先端の加工技術と高度な制御・駆動技術の融合が、
新たなものづくりを開拓します。**

The Fusion of Leading Edge Processing Technologies and
Advanced Control and Drive Technologies Opens up New Areas of Production

放電加工機【Electrical Discharge Machines】

形削ワイヤ放電加工機【Die-Sinking and Wire-Cut Electrical Discharge Machines】

形削ワイヤ放電加工機では、業界トップレベルの高速度加工、安定性、優れた操作性で生産効率を向上。さらに、加工経路確認や複製状況確認、メンテナンス状況の確認などのモニタリングが可能です。

Mitsubishi Electric's wire-cut and die-sinking electrical discharge machines deliver the industry's highest standards of speed, stability and ease of operation to increase production efficiency. The processing status of the job, operating status data, and maintenance conditions can all be monitored.



Jet Engine

細穴放電加工機【Fine-Hole Drilling EDMs】

ドリルによる切削加工が困難な高アスペクト比の細穴を加工する部品加工分野対応の細穴放電加工機は標準です。

Mitsubishi Electric manufactures fine hole drilling EDMs for parts processing fields that require fine holes of high aspect ratio, which are difficult to machine using drills.



レーザ加工機【Laser Processing Machines】

金属切断用レーザ加工機【Sheet Metal Laser Cutting Machines】

加工物はあらゆる形状・寸法・厚さまでを高精度で切断する性能により、多角で高精度な加工や二次処理・サニタリー加工といった幅広い製品ラインアップを実現。フレキシブルな加工ソリューションをお届けします。

Mitsubishi Electric's industrial applications, which have evolved as to develop cost-effective and current demand in addition to processing machines, have evolved on innovation lineup of sheet metal, high precision processing machines and 2D and 3D laser processing machines that offer flexible production solutions.



EUV Lithography

基礎穴あけ用レーザ加工機【Laser Drilling Machines】

携帯電話やデジタルカメラなどの機械で使われている、高密度プリント基板やICパッケージ用プリント基板の基盤を構成させる微細穴を高速加工する。基礎穴あけ用レーザ加工機です。独自の高出力光源と高度な光学技術により、生産性を大幅に向上しています。

Mitsubishi Electric's laser drilling machines offer high-speed drilling of fine holes that maintain excellent accuracy between the different layers of printed circuit boards used in IC packages and high-density printed circuit boards in a variety of IT applications, including cell phones and digital cameras. Our unique high-power laser sources and advanced optical technologies bring long-term increases in productivity.

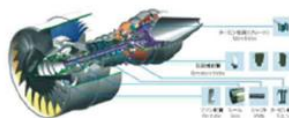


Smart Phone

MSコーティング技術【MS Coating】

非常に熱、酸腐や磨耗のない高耐久性な表面処理技術で、耐久性、耐摩耗性に優れた機械部品を加工して形成できます。また、加工工程の簡便化により大幅なコスト削減が可能です。航空機ジェットエンジン部品や自動車・家電機器への応用が期待されている加工技術の技術です。

MS Coating is a groundbreaking electrical discharge surface treatment technology that does not cause peeling or cracking of metals. Further, it allows stable formation of functional films that display excellent durability and wear resistance. Mitsubishi Electric's unique technology also significantly reduces costs by streamlining the production process, and its range of applications is expected to expand benefits to include jet engine components, automobiles, and power.



電子ビーム加工機【Electron Beam Machines】

結核電線・合金化・表面改質などの加工にのみならず加工に適用されており、特に自動車製造業を代表とした各種工業分野に付加価値の高い新たなアプリケーションを開発しています。現在では電子デバイス製品のマイクロ加工などIT産業の先端分野にも適用分野が豊富に広がっています。

Used in a variety of precision heat processing welding, drying, and surface modifications in various industries, Mitsubishi Electric's electron beam machines present new, high value-added applications in various industrial fields, and the automotive industry in particular. The applications of electron beam machines are also expanding to advanced segments of the IT industry, where they are essential in the micro-welding of electronic device components.



3D Printing

数値制御装置【Computerized Numerical Controllers (CNCs)】

産業界のマザーマシンと呼ばれる工作機械の中枢を担う制御装置です。最新のFSC-CNC、高速光サーボモーターを搭載し、高速高精度加工を実現します。自動車業界・IT業界をはじめとした各種産業の生産性向上に貢献します。

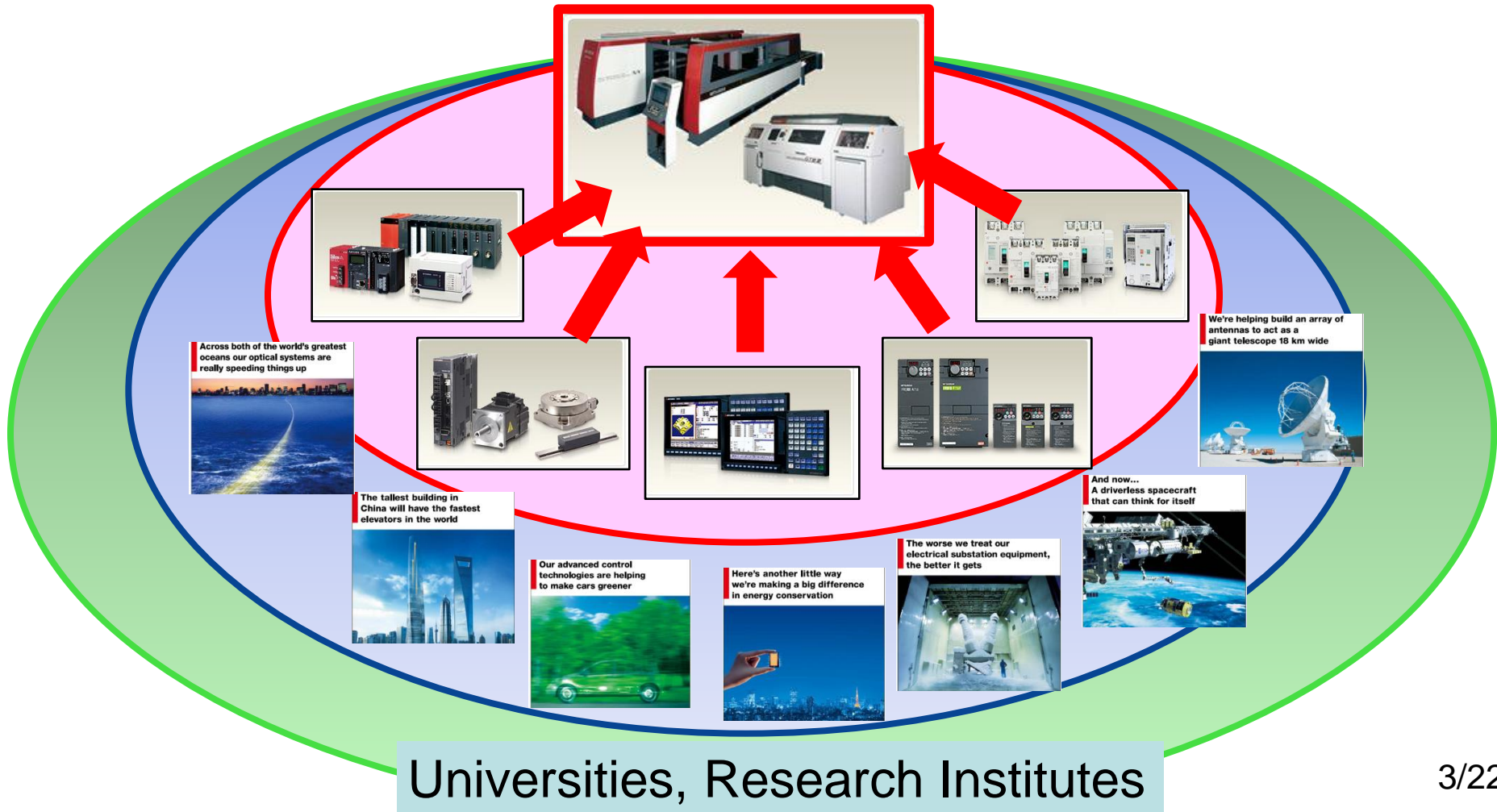
CNCs are the core of machine tool systems, which are commonly called the "mother machine" in the manufacturing industry. Mitsubishi Electric's CNCs are equipped with the latest FSC-CNC and high-speed servo motor system, to provide high speed and high-precision machining. They contribute to increasing productivity in the automotive and IT industries, as well as in a wide variety of other industries.



Smart Phone

1. Who we are

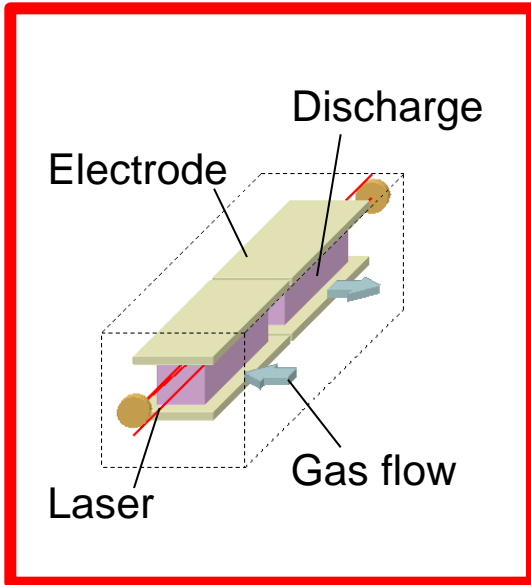
We are constructing eco-systems including a variety of in-house technologies, universities, and research institutes



2. Advantage of our CO₂ lasers

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Transverse-gas-flow CO₂ lasers vs. other CO₂ lasers

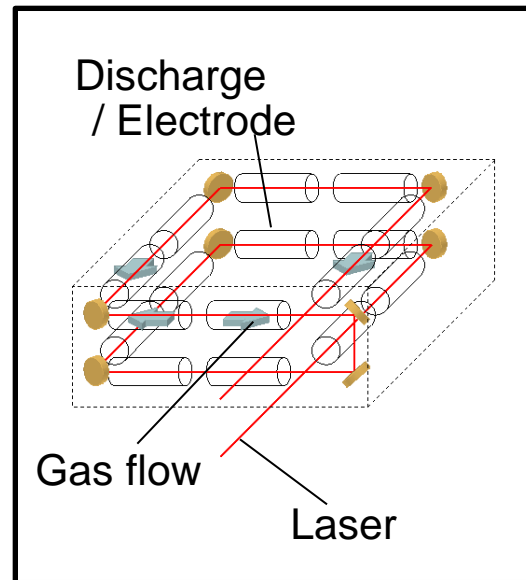


1. Transverse-gas-flow

Low flow
Short length
Broad area

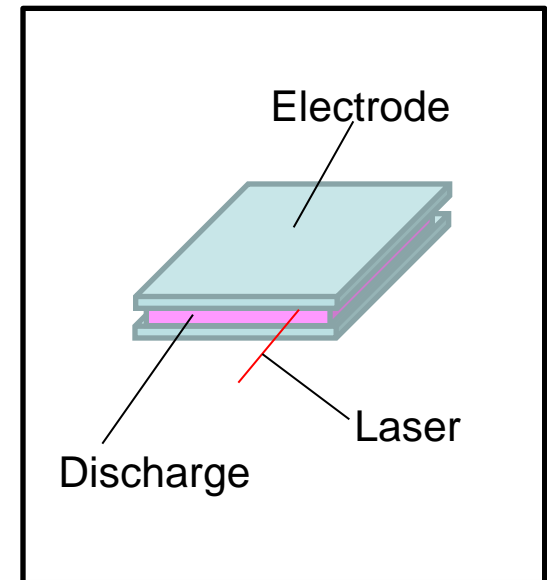


High-gain & Low-loss



2. Fast-axial-flow

Fast flow
Long length
Small area

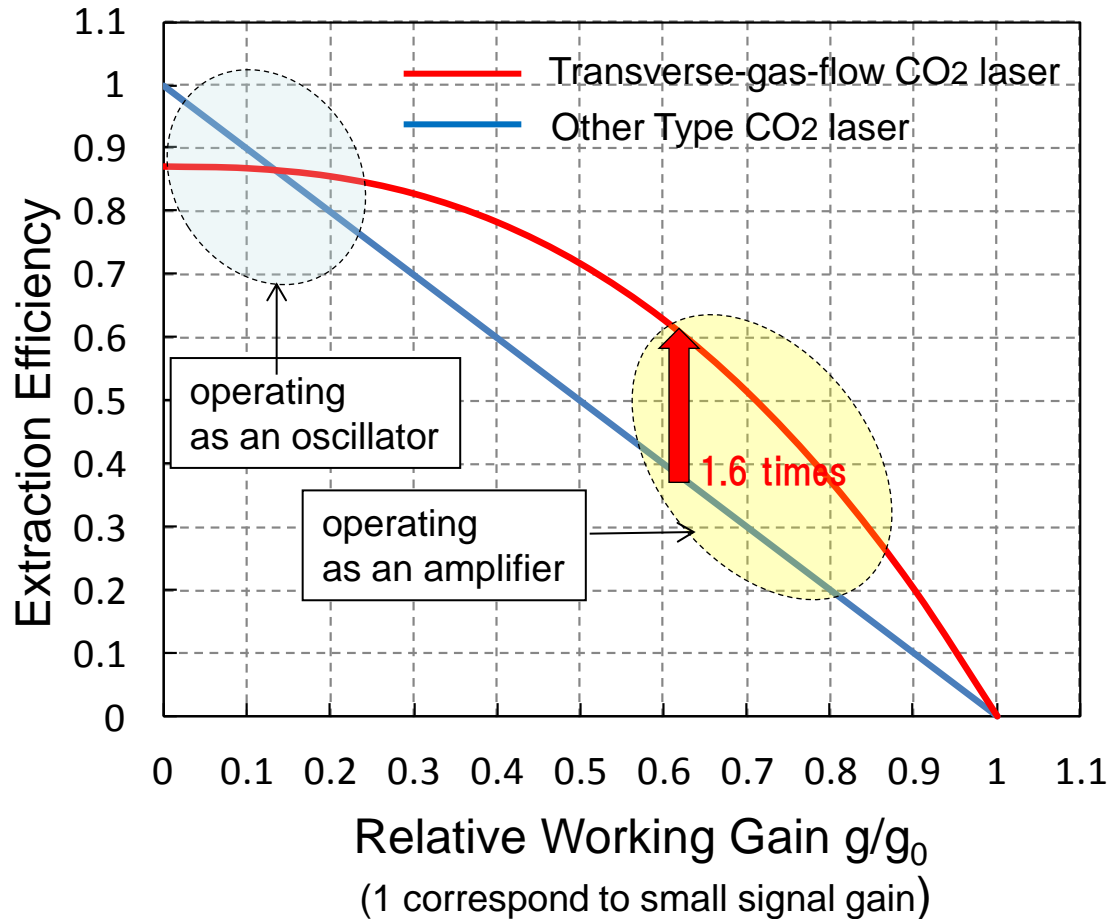


3. No-flow

No flow
Short length
Wide area

2. Advantage of our CO₂ lasers

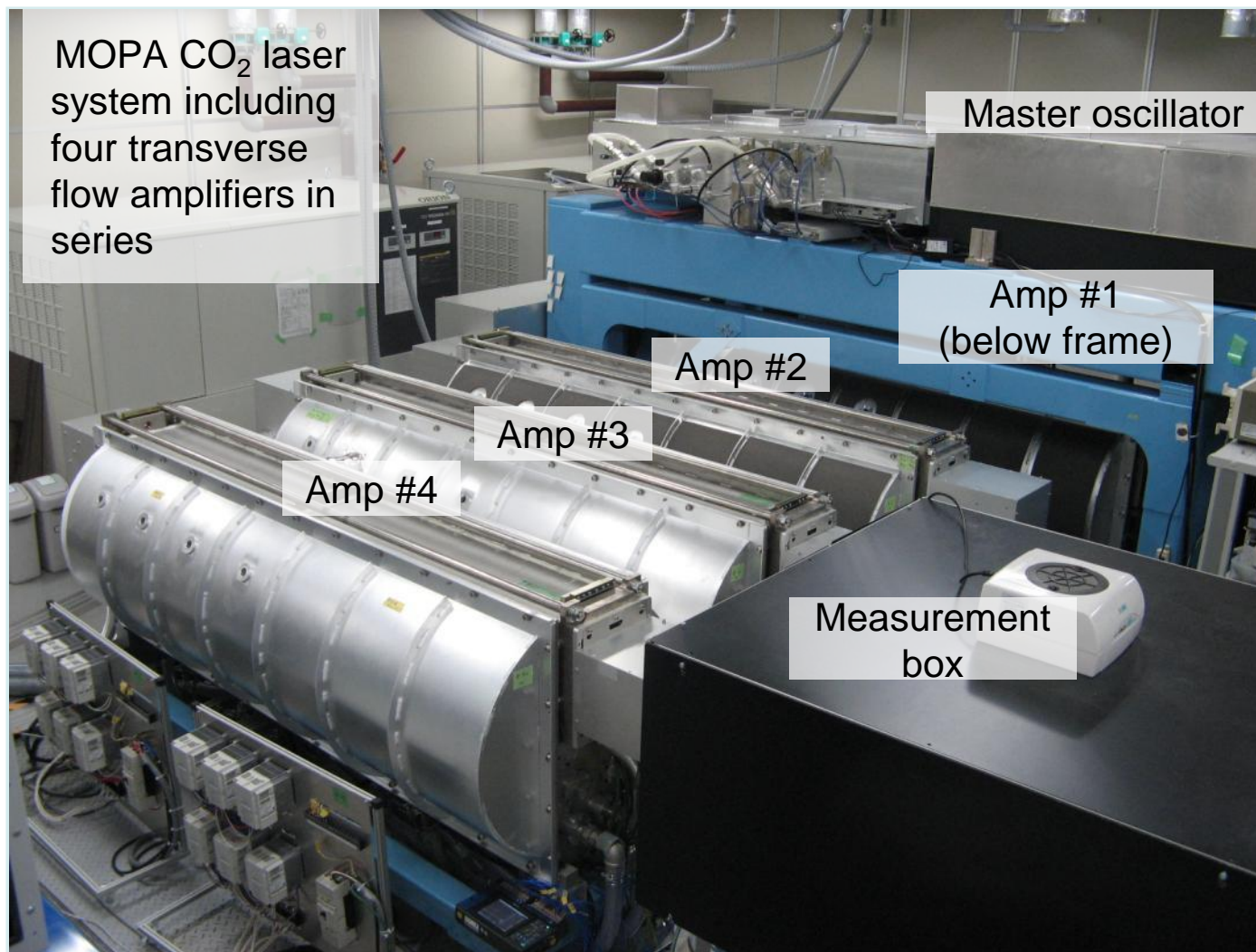
Theoretical calculation



3. Experimental results

3. Experimental results

Experimental setup



Operating conditions

- Electrical input powers for discharge: 100 kW x4, duty 100%
- Laser input: 15 ns, 100 kHz

Master Oscillator

Wavelength 10.6 μm P(18,20,22,24)

Repetition frequency 100 kHz

Pulse duration 15 ns

Amplifiers

Laser input 50 W max

Beam radius($1/e^2$) 6 mm@amp#1 ,
15 mm@amp#2-4

Electrical input 100 kW max x4

Discharge duty 100%

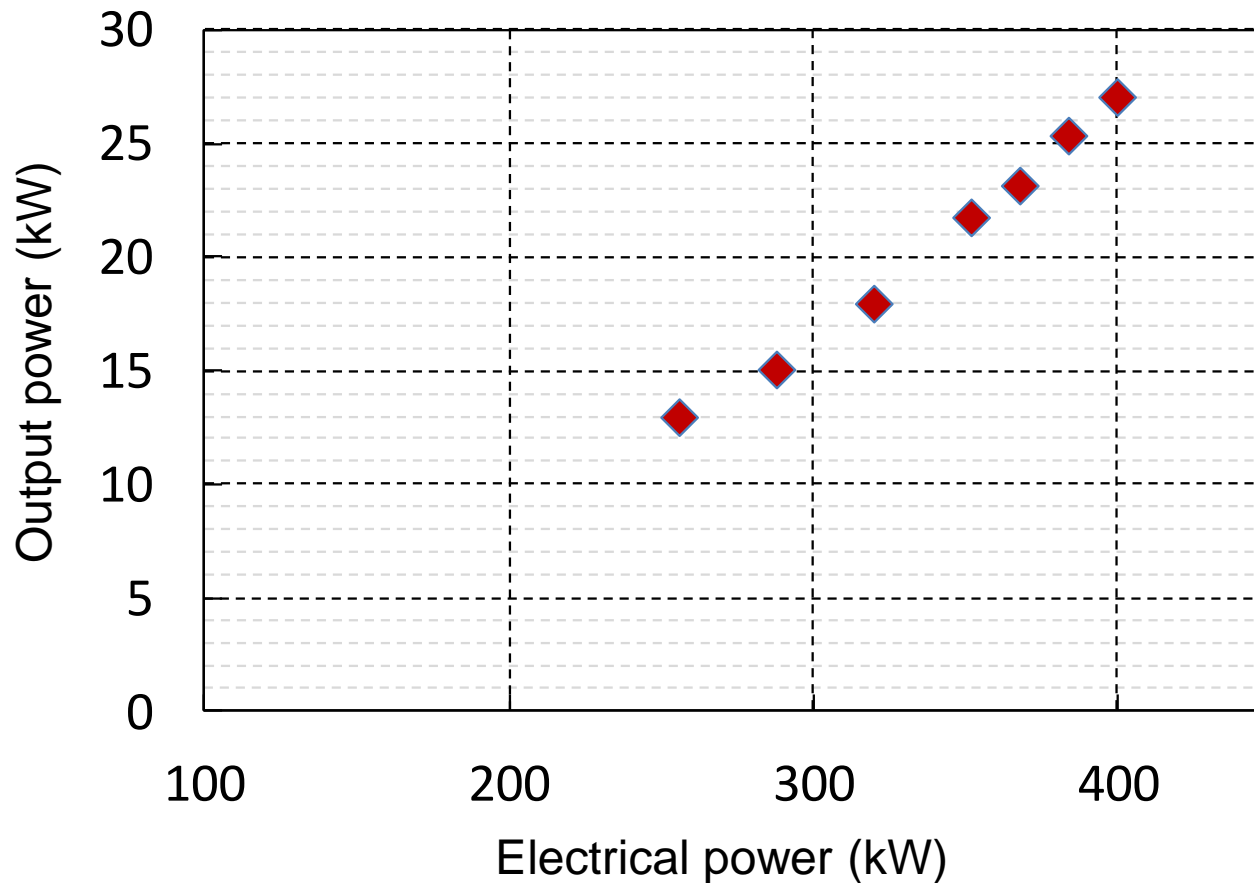
Discharge volume $5 \times 4 \times 188 \text{ cm}^3 \times 4$

Gas pressure 7.0 kPa

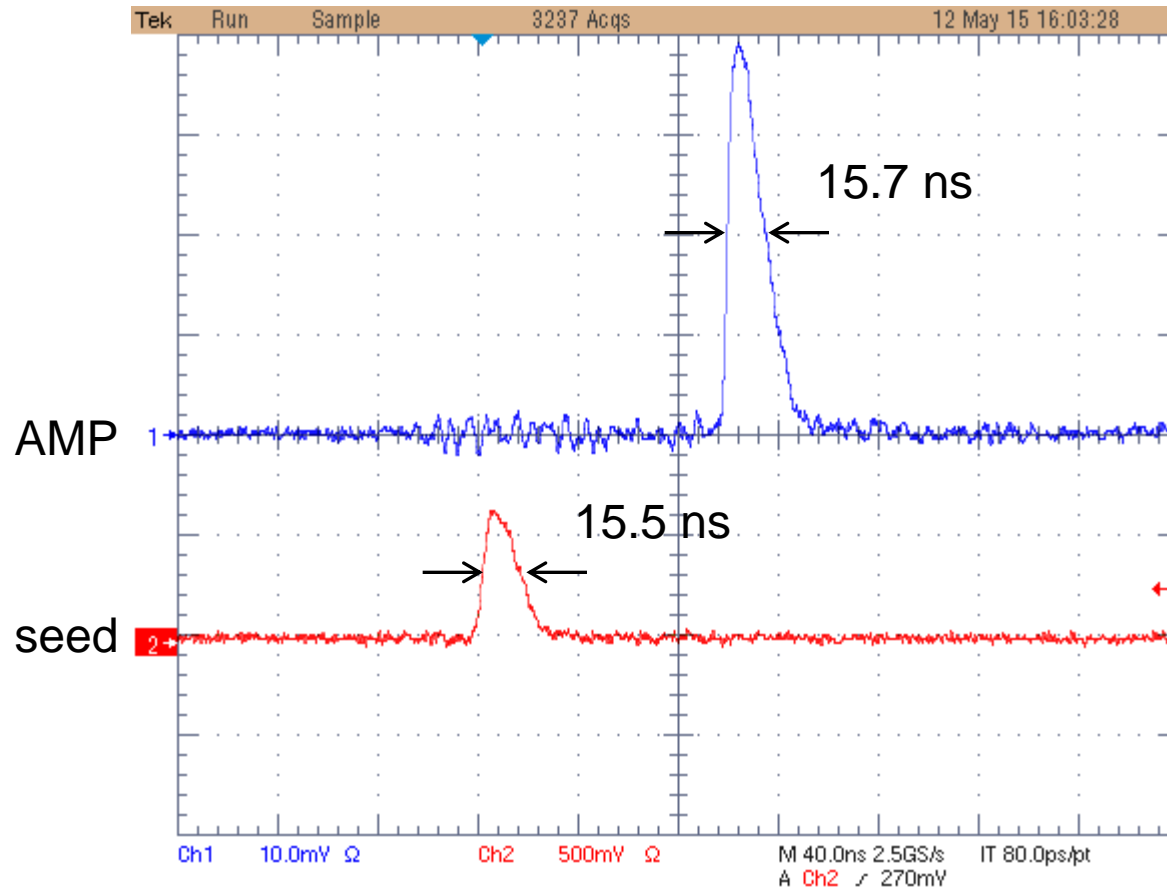
3. Experimental results

Four amplifiers driven by four-line oscillator

- Output power of 27 kW was demonstrated (duty 100%)



Pulse shape example



- Output pulse duration: 15.7 ns
- Linear amplification

Proto #2 System Layout

Mitsubishi pre-amplifier was installed in Proto #2 and performance was confirmed



Proto#2 layout

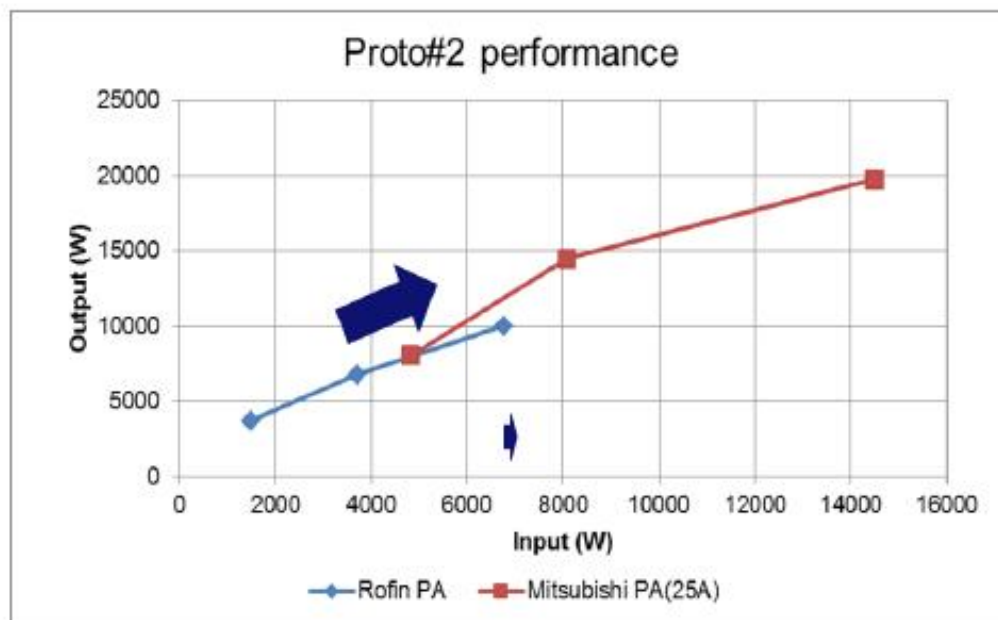


3. Experimental results

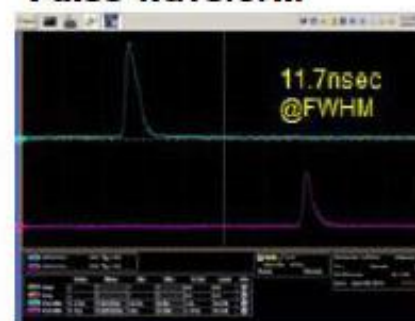
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High Power EUV Source with Mitsubishi Pre-Amp

- 20kW output power was achieved with Driver laser system with Mitsubishi pre-amplifier



Pulse waveform



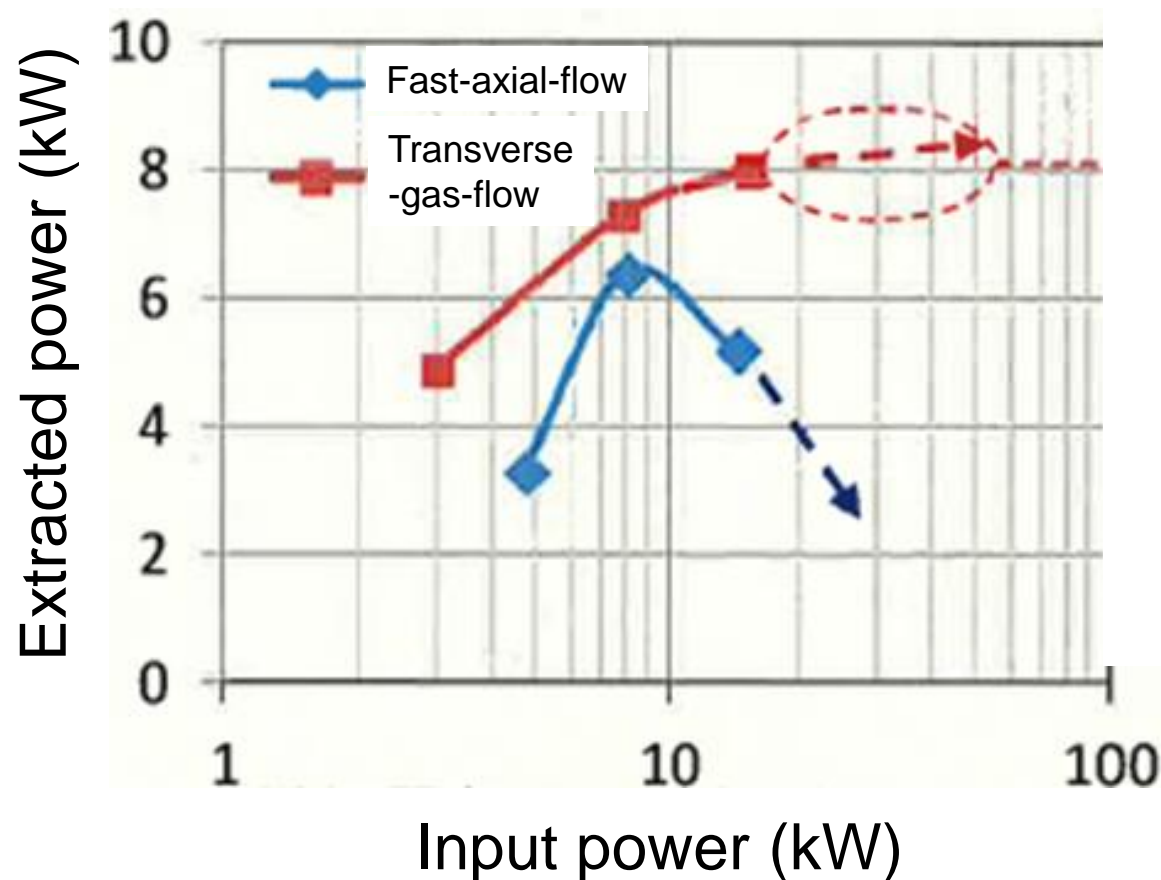
Beam Profile



4. Higher CO₂ power prospects

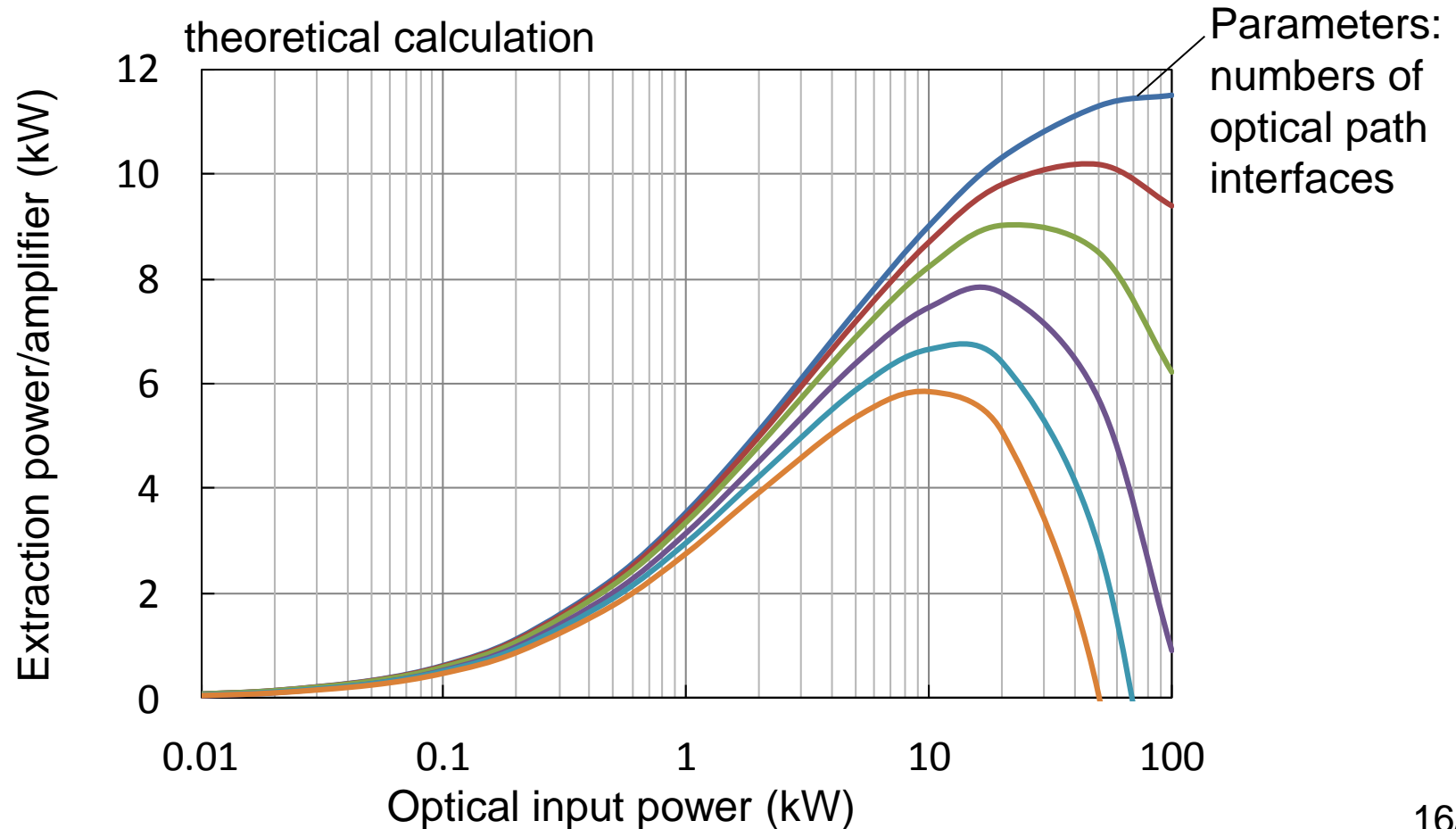
4. Higher CO₂ power prospects

Higher power extraction at higher input power
for transverse-gas-flow CO₂ laser



4. Higher CO₂ power prospects

Optical path interfaces must be reduced for efficient operation at high input power



4. Higher CO₂ power prospects

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CO₂ Driver Laser configuration for EUV Sources

	Target at Plasma	System	Oscillator	Pre-Amplifier	Main Amplifier		
Proto #1	5kW	Endurance Testing Platform	GPI	R	T	T	
	8kW	Power Up Testing	GPI	R	T	T	T
Proto #2	14kW	Power Up Testing	GPI	M	T	T	T
Under Construction Pilot #1							
	>20kW	Customer Beta Unit	GPI	M	M	M	M

validated performances at system

Proto Systems in Operation

Target System Specification

Operational Specification		Proto #1	Proto #2	Under construction Pilot #1
Target Performance	EUV Power	25 W	> 100 W	250 W
	CE	3%	4%	4%
	Pulse rate	100 kHz	100 kHz	100 kHz
	Output angle	Horizontal	62° upper (matched to NXE)	62° upper (matched to NXE)
	Availability	1 week operation	1 week operation	> 75%
Technology	Droplet generator	20 – 25 μm	20 μm	< 20 μm
	CO ₂ laser	> 8 kW	> 12 kW	25 kW
	Pre-pulse laser	picosecond	picosecond	picosecond
	Debris mitigation	validation of magnetic mitigation in system	10 days	> 30 days

5. Higher EUV power prospects

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Opinions as a technology solution provider

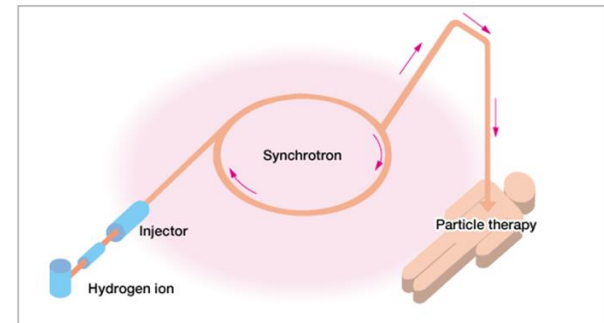
1. Industrial solid-state lasers

- Industrial fiber lasers are emerging
- Solid-state lasers, we need further enhancement of the efficiency to compete with CO₂ in TCO figures



2. Lasers based on synchrotron

- Medical applications are emerging
- Lasers based on synchrotrons need radical simpler configurations



Basic concept for particle therapy system



Synchrotron for proton beam



Synchrotron for carbon and proton beam

5. Higher EUV power prospects

Toward >500W or > 1kW EUV powers

1. If it is requested, we consider it is possible within the configuration we explained today

⇒ Add more CO₂ amplifiers and use Gigaphoton EUV technology



2. Another approach is to develop better reflective mirrors systems

⇒ Utilize academic brains: the University of Tokyo, supported by the Japanese government



<http://www.ipst.s.u-tokyo.ac.jp/iccpt/> 21/22

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Thank you very much for your attention
Thank you again for your invitation to this workshop